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LUNAR MODULE CONSUMABLES
ANALYSIS FOR MISSION
AS-505/CSM-104/LM-4

By Martin L. Alexander
and
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Guidance and Performance Branch



MISSION PLANNING AND ANALYSIS DIVISION



MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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MISSION AS-505/CSM-104/LM-4

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LUNAR MODULE CONSUMABLES ANALYSIS FOR MISSION AS-505/CSM-104/LM-4

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SUMMARY AND INTRODUCTION

A detailed analysis of the lunar module consumables budget for the primary rendezvous model to be used for mission AS-505/CSM-104/LM-4 is presented. While the rendezvous model is subject to change as the planning of the mission progresses, the material contained in this report is essential to defining the current approach to performing a consumables analysis including data sources, methods of calculation, and expected procedural details of the flight which affect the consumables usage. This analysis shows a positive margin of consumables remaining at the completion of the nominal mission.

A less detailed analysis of the alternate rendezvous model C-2 for the mission is included, and it too shows a positive margin of consumables remaining at the end of the nominal mission.

The factors most likely to change the results presented in this document will be (1) changes to the mission timeline, (2) improved data sources such as postflight data from missions preceding this one, or certain phases of this mission, and (3) details of the flight plan and crew procedures which may be different from those assumed here.

LM REACTION CONTROL SYSTEM PROPELLANT BUDGET

In order to check out the LM systems thoroughly in earth-orbital flights, mission models which depart considerably from the lunar landing mission have been proposed, resulting in LM consumables becoming the limiting factor for some models. In particular, LM activity while docked to the command and service modules (CSM) and firings of the descent propulsion system (DPS) in the rendezvous sequence may be quite expensive in usage of LM reaction control system (RCS) propellant for moment control. In order to fly this mission, the LM-RCS propellant usage adds one constraint to the mission, i.e., the alternate rendezvous model C-2 cannot be flown without utilizing ascent propellant through the interconnect in the RCS thrusters during the descent firings in the rendezvous sequence. While the primary rendezvous model B-2" could be flown without utilizing the interconnect, the RCS propellant margin at the completion of LM activity would be reduced by approximately 30 lb.

The LM RCS performs the following functions:

1. Provides small thrust impulses to stabilize the LM during burns of the descent and ascent propulsion systems.
2. Provides necessary thrust impulses to control the vehicle attitude (movement around an axis) and vehicle translation (movement along an axis) during such phases of the mission as rendezvous and docking maneuvers.
3. Provides necessary thrust impulses to accomplish the LM/CSM separation maneuver.
4. Provides necessary thrust impulse to accomplish acceleration for ullage settling in the descent and ascent propellant storage tanks, when required.

The primary sources of data are references 1, 2, and 3. Other data sources, where used, are referenced specifically. The accuracy of the parametric data in references 1, 2, and 3 is stated to be within ± 10 percent. Refinements to the data are expected to arise from postflight data derived from flights preceding this mission, actual simulations of portions of this mission, and further analyses.

The primary rendezvous model upon which this analysis is based may be found in table I and is the model B-2" rendezvous as defined October 17, 1967. Table II gives the quantity of LM-RCS propellant available for mission planning; table III gives a breakdown of LM-RCS propellant usage by blocks; this data is plotted in figure 1. These blocks are further broken down into individual events in table IV, which also provides a detailed list of the assumed flight plan, data sources, and method of calculation in obtaining the propellant usage numbers given here.

Table V gives the rendezvous timeline for the alternate rendezvous model C-2, and the LM-RCS propellant usage for this model is given in table VI.

ELECTRICAL POWER ANALYSIS

Since this particular flight is now slated to be flown with the LM-4 vehicle, a high energy consumer was omitted from consideration in this analysis. Presently, developmental flight instrumentation is not scheduled to be in any vehicle subsequent to LM-3. Since this equipment requires approximately 700 watts, both descent and ascent stage batteries on the LM-4 get a power draining reprieve in comparison to budgets performed on similar timelines in the past.

Assumptions played a vital role in the final determination of the electrical power usage for the B-2" rendezvous scheme of the LM-4 mission. The principal assumptions are listed below.

1. The RCS heaters will not necessarily be required during long phases after the thrusters have been fired. This assumption is documented in reference 4.
2. LM-4 will have no developmental flight instrumentation aboard.
3. Both a coarse and a fine inertial measurement unit (IMU) alignment were considered to be performed prior to a major maneuver when there was available time.
4. The RCS heaters were considered to be on continuously for an hour during initial warm-ups, as is recommended by reference 5.
5. As found in reference 6, the total energy capacity of the descent and ascent batteries is 46.9 and 17.8 kilowatt-hours, respectively.
6. No guidance and navigation (G&N) equipment was assumed to be in the operational mode during the first checkout period of the LM.
7. All LM rendezvous equipment was turned on just subsequent to LM/CSM separation.
8. LM checkout time was assumed to be approximately 2 hours.
9. Descent and ascent stage batteries were assumed to have 1.9 and 1.1 kilowatt-hour redlines, respectively. This assumption is documented in reference 7.

Table VII presents, in comprehensive detail, the analysis supporting the data found in figures 2 and 3. This particular table identifies every energy level considered in preparation of the power profiles displayed in these figures. The "Remarks" column gives justification to the deviation in energy levels found in references 1, 2, and 3 from those obtained in table VII.

Figure 4 displays the average electrical power levels for the principal phases of this mission. From this information, one may perform hasty feasibility checks in order to determine if slight perturbations to the current timeline can be accommodated by LM batteries.

CONCLUSIONS

Rendezvous model B-2", the primary rendezvous model, for the nominal AS-505/CSM-104/LM-4 mission results in positive margins for both RCS propellant and LM electrical power at the termination of the LM-active rendezvous phase. In particular, the LM-RCS propellant margin at the completion of docking is 79 lb, and the ascent stage batteries have approximately 10.2 kilowatt-hours of electrical energy remaining at the same critical time of the mission. The margin at the completion of docking is particularly significant as this is the point in the mission at which the crew returns to the command module for the final time. Of secondary importance is the maximum time from final LM/CSM separation in which the ascent stage batteries can support an inertially stable platform for the purpose of a CSM flyby exercise. This time is 6 to 7 hours, while the LM descent stage has 5.9 kilowatt-hours of electrical energy remaining at the nominal time of staging.

Rendezvous model C-2 (alternate rendezvous scheme) results in an RCS propellant margin of 47 lb and an ascent stage electrical energy margin of 9.3 kilowatt-hours at the completion of docking. For this particular rendezvous plan, the ascent stage can remain an adequate passive vehicle for a later CSM flyby if the exercise is terminated within 5 to 6 hours subsequent to separation. Ascent stage battery depletion places the above constraint on the CSM-active portion of the proposed rendezvous plan. Descent stage batteries have depleted to the 7.5 kilowatt-hour energy level at the nominal time of staging in the C-2 model.

Each of the above margins represents the planning or useable level of consumables remaining at a particular time in the mission.

TABLE I.-- MODEL B-2" RENDEZVOUS

[October 17, 1967]

Time, hr:min	Maneuver	System	Δt , sec
93:36	Initial phasing	DPS	75
94:06	1st CSI	RCS	15
96:11	1st CDH	DPS	33
98:13	2nd CSI	APS	3.5
98:58	2nd CDH	APS	3.5
99:31	TPI	RCS	25
	TPF	RCS	100

TABLE II.-- LM-RCS PROPELLANT AVAILABLE FOR MISSION PLANNING^a

Maximum loaded propellant, lb	638
Unusable propellant:	
Loading and temperature dispersions, lb	10
Trapped and unexpelled, lb	40
Minimum deliverable propellant, lb	
Mixture ratio uncertainty, lb	30
Gaging accuracy, lb	64
Total available propellant for mission planning, lb . . .	
	494

^aReference 8

TABLE III.- LM RCS PROPELLANT USAGE

Block	Propellant, lb
First docked DPS burn	33.4
Second docked DPS burn	66.8
Inspection	10.0
Rendezvous:	
DPS phasing burn	19.8
CSI 1 (RCS burn)	22.5
CDH 1 (DPS burn)	19.3
Staging	2.0
CSI 2 (APS burn)	12.1
CDH 2 (APS burn)	12.1
TPI (RCS +x)	29.0
TPF (RCS +z)	90.8
Docking	52.5
Propellant for attitude maneuvers during rendezvous	34.0
LM tracking of CSM during rendezvous	10.0
Attitude hold for CSM flyby	<u>8.0</u>
Total	422.3

TABLE IV.- NOMINAL LM RCS PROPELLANT BUDGET FOR MODEL B-2" RENDEZVOUS

Block	Event	Required maneuver	Comments	Propellant, lb
First DPS Burn			Current Mass Properties: CSM/LM Wt = 59,220 I_{xx} = 37,000 I_{yy} = 340,000 I_{zz} = 342,000	
IMU Orientation Determination	CSM Activity	—		
IMU Fine Align	Simultaneous rotational maneuver, PGNS at $0.5^\circ/\text{sec}$ (docked)	5.8		
	Attitude hold: 4 hours in max deadband	.6		
	Switch max to min deadband	2.9	Propellant requirement taken as $\frac{1}{2}$ that of a simultaneous rotational maneuver.	
Orient to burn Attitude	Simultaneous rotational maneuver, PGNS at $0.5^\circ/\text{sec}$ (docked)	5.8		
Ullage	4 jets - 8 seconds	12.0	Increase to nearest whole second	
	Start transient	1.5	Start transient for first DFS burn from MDDB. Control during burn estimated	

TABLE IV.- NOMINAL LM RCS PROPELLANT BUDGET FOR MODEL B-2" RENDEZVOUS - Continued

Block	Event	Required maneuver	Comments	Propellant, lb
	RCS control during burn		from Grumman FMES test (LM-1 undocked) No data available for docked burn (ref. 9).	4.3
	Shutdown transient		Extrapolated from 202 postflight data	.5
Second DPS burn	Max deadband hold 2 hours			.3
	IMU Fine Align			5.8
	Switch max to min deadband			2.9
	Orient for burn	Docked maneuver at $0.5^{\circ}/sec.$		5.8
	Ullage	4 jets - 8 seconds		12.0
	Start transient	Gimbal is trimmed to c.g. from previous DPS burn, start transient is reduced.		0.5

TABLE IV.- NOMINAL LM RCS PROPELLANT BUDGET FOR MODEL B-2" RENDEZVOUS - Continued

Block	Event	Required maneuver	Comments	Propellant, lb
	RCS control during long DPS burn	RCS for control during burn estimated from Grumman FMEES test data (LM-1 undocked). No data available for docked operation.	39.0	
	Shutdown transient			
	CSM/LM Separation	Current Mass Properties: LM Wt = 17,000 lbs. $I_{xx} = 13,000$ $I_{yy} = 13,500$ $I_{zz} = 16,500$	Propellant allocation Maneuvers for station keeping and inspection require detailed study or simulation	10.0
	Inspect SPS nozzles and LM landing pads			

TABLE IV.- NOMINAL LM RCS PROPELLANT BUDGET FOR MODEL B-2ⁿ RENDEZVOUS - Continued

Block (Time)	Event	Required maneuver	Comments	Propellant, 1b
Initial DPS Phasing Burn (93:36)	Track CSM during rendezvous	6 orientation maneuvers + 6 ¹ hrs of 5° deadband hold		10.0
	75 second DPS burn @ 10% Throttle	1100 pounds DPS propellant at start of burn.		
	IMU Alignment			1.0
	Orient to burn attitude			.5
	Ullage		Ullage 8 seconds to settle APS propellants; open inter-connect; continue to ullage to settle DPS propellants, total ullage req'd = 17 seconds. APS interconnect propellant for control during burn. Close inter-connect 10 sec. prior to shutdown.	12.0
	RCS Control (last 10 seconds of burn & shutdown transient)		Estimate	2.0
	Post-burn trim with RCS	Orientation + 2 fps trim		4.3
CSI 1 (94:06)	RCS burn	Orient to burn attitude 15 seconds, 4 jets, +x	Burn not long enough to open APS inter-connect because of ullage and early closing of interconnect requirements	•5 22.0

TABLE IV.- NOMINAL IM RCS PROPELLANT BUDGET FOR MODEL B-2["] Rendezvous - Continued

Block (Time)	Event	Required maneuver	Comments	Propellant, lb
CDH 1 (96:11)	DPS burn			.5
	Fine align IMU			.5
	Orient to burn attitude			
	Uillage		See comment for previous DPS burn ullage	12.0
	RCS Control (last 10 seconds of burn & shutdown transient)			2.0
	Post-burn trim with RCS			4.3
Stage	Orientation + 1 fps ΔV		Current Mass Properties	2.0
CSI 2 (98:13)	APS burn (3.5 sec)		W _I ≈ 11,000 I _{xx} ≈ 6,500 I _{yy} ≈ 3,500 I _{zz} ≈ 6,000	.4
	Fine Align IMU			
	Orient to burn attitude			
	Uillage		4 second ullage	6.0
	RCS control during burn		.5 #/sec, based on burnout CG of y = 0, z = 3.8, cant angle = 2.5°	1.8
	Shutdown transient & Post burn trim			3.5

TABLE IV.- NOMINAL LM RCS PROPELLANT BUDGET FOR MODEL B-2" RENDEZVOUS - Continued

Block (Time)	Event	Required maneuver	Comments	Propellant, lb
CDH 2 (98:58)		APS burn (3.5 sec)		12.1
TPI (99:31)	RCS +x burn Fine Align IMU Orient +x translation $\Delta V = 23.3 \text{ fps}$	$\Delta V = 23.3 \text{ fps}$	•4 •4 Could save 7 lbs of RCS propellant by opening APS inter- connect briefly	28.2
TPF (~100:30)	RCS +z burn Fine Align IMU Orient Z axis burn	$\Delta V = 52.6 \text{ fps}$	•4 •4 90.0	34.0 Scaled down by the average ratio of moments of inertia from G&C simulations (CSM active rendezvous with 3 fps error @ TPI). Should be up- dated when LM active rendezvous simulation data becomes available.

TABLE IV.- NOMINAL LM RCS PROPELLANT BUDGET FOR MODEL B-2" Rendezvous - Concluded

Block (Time)	Event	Required maneuver	Comments	Propellant, lb
Docking			Scaled up for mass properties of full LM ascent stage from 6-DOF simulations referenced in MMDB. This is "mean" propellant requirement	52.5
Attitude hold for CSM Flyby		Hold max deadband 6 hr	Through completion of CSM flyby	8.0
			Total usage through docking = 414.3	
			Total usage = 422.3	
			Available for mission planning = 494.0	
			Margin after docking = 79.7	
			Margin at end of mission = 71.7	

TABLE V.- MODEL C-2 LM-ACTIVE RENDEZVOUS

Event	G.e.t., hr:min	ΔV , fps	t_B , sec	System
Separation	94:13	26	17.4	DPS
CSI ₁	95:20	25	16.7	DPS
CDH ₁	95:59	44	26	DPS
1st Phase	96:53	100	67	DPS
2nd Phase	98:25	208	37	DPS
Insertion	99:10	72	6.6	APS
CSI ₂	99:40	60	5.8	APS
CDH ₂	100:18	55	5.4	APS
TPI	100:50	21		RCS
Braking	101:25	24		RCS

TABLE VI.- NOMINAL LM RCS PROPELLANT BUDGET MODEL C-2 RENDEZVOUS

Time, hr:min	Event	Required maneuver	Comments	Propellant, 1b
	Subtotal		Same as Model B2" rendezvous	110.2
	Track CSM during rendezvous			10.0
94:13	DPS separation burn	Increase separation $\Delta V = 26$ fps $t_B = 17.4$ fps Typical DPS burn utilizing interconnect	LM wt = 16 000 1b $I_{xx} = 12\ 000$ $I_{yy} = 12\ 500$ $I_{zz} = 15,500$	19.8
95:20	CSI ₁	DPS burn, $\Delta V = 25$, $t_B = 16.7$		19.3
95:59	CDH ₁	DPS burn, $\Delta V = 44$, $t_B = 26.$		19.3
96:53	1st phasing burn	DPS burn, $\Delta V = 100$, $t_B = 67.$		19.3
98:25	2nd phasing burn Stage	DPS burn, $\Delta V = 208$, $t_B = 37.$		19.3
99:10	Insertion	APS burn, $\Delta V = 72$, $t_B = 6.6$	Typical APS burn utilizing interconnect	2.0
99:40	CSI ₂	APS burn, $\Delta V = 60$, $t_B = 5.8$		12.1

TABLE VI.- NOMINAL LM RCS PROPELLANT BUDGET MODEL C-2 RENDEZVOUS - Concluded

Time, hr:min	Event	Required maneuver	Comments	Propellant, lb
100:18	CDH ₂	APS burn, $\Delta V = 55$, $t_B = 5.4$		12.1
100:50	TPI	X axis RCS burn, $\Delta V = 21$		26.6
	MCC	$\Delta V = 11$		18.4
101:25	Braking	$\Delta V_{est} = 37$	Attitude maneuver, attitude hold during rendezvous	60.0
	Docking			52.5
	Attitude hold for CSM flyby			8.0

Total usage through docking 447.

Total usage 455.

Available for mission planning 494.

Margin after docking 47.

Margin at end of mission 39.

TABLE VII.— LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/104/LM-4 MISSION

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, hr	Block rate \times 7.12%, watts	5 \times 6, watt-hr	Block energy, watt-hr	$7 + 8 =$ total energy, watt-hr	Remarks	
Countdown	L26-4 Translunar Coast	-00:30:00	.5	.5	143.3	--	71.7	71.7	Des., Phase 1	
Launch & Earth Orbit	L26-4 Translunar Coast	00:00:00	3.583	1.951	1.632	89.4	145.9	174.4	Des., Phase 2	
Prior to SLA Deploy	L26-4 Translunar Coast	03:34:59	1.183	.301	.882	120.8	106.5	36.4	Des., Phase 3	
SLA Deploy to CSM	L26-4 Translunar Coast	04:45:58	36.233	--	36.233	95.2	3449.4	--	142.9 Des., Phase 3	
Power Transfer	L26-4 Translunar Coast								3449.4 CSM, Phase 5	
LM Power Off Coast										
Clear Tunnel &	JL2-3 INV to LM	41:00:00	.214	.214	--	123.0	--	26.3	26.3 CSM, Phase 1	
Transfer 1st Crew-	JL2-3 INV to LM	41:12:50	.2	.2	--	815.6	--	163.1	163.1 Des., Phase 2	
man to LM	JL2-3 INV to LM	41:24:50	.211	.211	--	787.8	--	166.3	166.3 Des., Phase 3	
Transfer Electrical	JL2-3 INV to LM									
Power & Cabin										
Habitability Check										
Transfer to IM ECS	JL2-3 INV to LM									
& Complete Crew										
Transfer to IM										
C/O Two Men	JL1+3 Orbital c/o	41:37:30	.517	.278	.239	891.1	213.0	247.7	460.7 Des., 1st Period,	
									-205.3 for RCS heaters	
									off, -70.4 for G&N off,	
									-888.3 for DFI off	
C/O Two Men	JL1+3 Orbital c/o	42:08:29	.543	.304	.239	1015.3	242.7	308.7	551.4 Des., 2nd Period,	
									-205.3 for RCS heaters	
									off, -219.8 for G&N	
									off, -688.3 for DFI	

TABLE VII.- IM ELECTRICAL POWER ANALYSIS FOR THE AS-505/LM-4 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, hr	Block rate × 7 1/2% watts	5 × 6 watt-hr	Block energy, watt-hr	7 + 8 = total energy, watt-hr	Remarks	2
C/O Two Men	JL1-3 Orbital C/O	4:24:41:03	.495	.256	.239	943.3	225.4	241.5	466.9	Des., 3rd Period, -205.3 for RCS heaters off, -625.8 for G&N off, -688.3 for DFI off
C/O Two Men	JL1-3 Orbital C/O	4:31:04:42	.447	.208	.239	941.9	225.1	195.9	421.0	Des., 4th Period, -205.3 for RCS heaters off, -759.6 for G&N off, a Δt of 1 hr was added to the block
Prep for EVA	L32-3 Docked EVA	4:31:37:31	1.954	1.042	.912	878.7	801.4	915.6	1717.0	Des., Phase 1, Δt=57.5 min for the EVA Prep, -205.3 for the RCS heaters off, -81.2 for G&N off
EVA	L32-3 Docked EVA	4:51:30:00	3.0	.217	2.783	809.7	2253.4	175.7	2429.1	Des., Phase 2, -205.3 for RCS heaters off, -81.2 for G&N off
Post EVA Activities	L32-3 Docked EVA	4:8:30:00	1.0	.408	.592	884.9	523.9	361.0	884.9	Des., Phase 3, -205.3 for RCS heaters off, -81.2 for G&N off
Two Men in LM on IM ECS	J33-4 Crew Transfer From LM to CSM	4:9:30:00	.05	.05	--	628.3	--	31.4	31.4	Des., Phase 1, +10.6 for the DES ECA being off, -150.5 for turn- ing the RCS heaters off, +40.2 for RR heaters on, -460.5 for G&N off, +18.5 for IR heaters on
One Man in LM on IM ECS	JL3-4 Crew Transfer From LM to CSM	4:9:33:00	.017	--	.017	628.3	10.7	--	10.7	Des., Phase 2 (Same remarks as those for time of 4:9:30:00)

TABLE VII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS--505/104/LM-4 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, 3 - 4 hr	Block rate \times 7 1/2%, watts	5×6 <td>Block energy, watt-hr</td> <td>$7 + 8 =$ total energy, watt-hr</td> <td>Remarks</td> <td>3</td>	Block energy, watt-hr	$7 + 8 =$ total energy, watt-hr	Remarks	3
SE in LM on CSM-ECS (water boiler dry-out)	L21.2 Subsystem Deactivation	49:34:00	1.375	.228	1.147	974.3	1117.5	222.1	1339.6 Des., -695.7 for DFI, -79.6 for ASA off, -21.5 for IMU electronics off, -38.2 for GASTA off, -80.5 for att. & control assay off, -2.7 for mission timer off, +263.3 for tracking light on	
One Man in LM on CSM ECS (waiting)	J13.4 Crew Transfer From LM to CSM	50:56:30	.058	--	.055	413.1	24.0	--	24.0 Des., Phase 3, (Same remarks as those for time of 49:30:00	
LM Power Off Coast	L26.4 Translunar Coast	51:00:00	17.5	--	17.5	95.2	1666.0	--	1666.0 CSM, Phase 5	
Transfer 1st Crewman to LM	JL2-3 INV to LM	68:30:00	.097	--	.097	123.0	11.9	--	11.9 CSM, Phase 1	
Transfer Electrical Power & Cabin Habitability C/O	JL2-3 INV to LM	68:35:50	.2	.2	--	315.6	--	163.1	163.1 Des., Phase 2	
Transfer to LM ECS & Complete Crew Transfer	JL2-3 INV to LM	68:47:50	.211	.211	--	787.8	--	166.3	166.3 Des., Phase 3	
C/O Two Men	JL4-3 Orbital C/O	69:00:30	.517	.278	.239	1782.8	426.1	495.6	921.7 Des., 1st Period, +616.0 for RCS heater warmup, -668.3 for DFI off	
C/O Two Men	JL4-3 Orbital C/O	69:31:29	.543	.304	.239	170.1	351.4	447.0	798.4 Des., 2nd Period, -688.3 for DFI on	
C/O Two Men	JL4-3 Orbital C/O	70:04:03	.495	.256	.239	2390.0	571.2	611.8	1183.0 Des., 3rd Period, +616.0 for RCS heater warmup, -658.3 for DFI off	

TABLE VIII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/10B/LM-4 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, 3 - 4 hr	Block rate, $\times 7\frac{1}{2}\%$, watts	5 \times 6 watt-hr	Block energy, watt-hr	7 + 8 = total energy, watt-hr		Remarks
Coarse IMU Alignment	J11-2 Docked IMU Alignment	70:33:22	.185	.085	.1	1798.9	179.9	152.9	332.8	Des., $\Delta t=6$ min for turning telescope 180° at .59 sec, -695.7 for DFI off
C/O Two Men	J11-3 Orbital C/O	70:44:37	.447	.208	.239	1906.8	455.7	396.6	852.3	Des., 4th period, -683.3 for DFI off, a Δt of approximately 1 hr was added to the block
Coasting	L27-4 Powered Up Coasting Flight	71:11:26	.867	--	.867	1951.0	1691.5	--	1691.5	Des., Phase a
Fine IMU Alignment	J11-2 Docked IMU Alignment	72:03:27	.194	.144	.05	1819.9	91.0	262.1	353.1	Des., $\Delta t=3$ min for turning telescope 90° at .59 sec, -695.7 for DFI off
Prep for Burn	J19-2 Descent Burn Docked	72:15:17	.203	.203	--	1883.9	--	383.4	383.4	Des., -695.7 for DFI off
Batteries Parallelled	J19-2 Descent Burn Docked	72:27:28	.083	.083	--	1899.7	--	78.9/78.9	78.9/78.9	Des./Asc., batteries paralleled, -695.7 for DFI off
Descent Burn	J19-2 Descent Burn Docked	72:32:28	.008	--	.002	2154.5	8.6/316	--	8.6/8.6	Des./Asc., batteries paralleled, $\Delta t=26$ sec for burn, +25.6 sec for DPS on, -695.7 for DFI off
Batteries Parallelled	J19-2 Descent Burn Docked	72:32:56	.083	.083	--	1899.7	--	78.9/78.9	78.9/78.9	Des./Asc., (Same remarks as those for time of 72:27:28)
Post Burn C/O	J19-2 Descent Burn Docked	72:37:56	.096	.056	--	1968.9	--	181.3	181.3	Des., (Same remarks as those for time of 72:15:17)

TABLE VII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS-5/05/104/LM-1 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, hr	Block rate $\times 7\frac{1}{2}$, watts	5×6 watt-hr	Block energy, watt-hr	$7 + 8 =$ total energy, watt-hr	Remarks	
Coasting	J27-4 Powered Up Coasting Flight	72:43:41	.775	--	.775	1951.0	1512.0	--	1512.0	Des., Phase a
Fine IMU Alignment	J11-2 Docked IMU Alignment	73:30:10	.154	.144	.05	1819.9	91.0	262.1	353.1	Des., (Same remarks as those for time of 72:03:27)
Prior to DPS Burn	J10-4 Powered Descent & Landing	73:41:50	.125	.125	--	2004.4	--	250.6	250.6	Des., Phase 1, -19.5 for RR off, the LR was assumed to be on for the entire block
Prior to DPS Burn	J10-4 Powered Descent & Landing	73:49:20	.128	.128	--	2036.2	--	130.3/130.3	130.3/ 130.3	Des./Asc., Phase 2, -146.2 for RR off, +21.4 for RR heaters on, asc. & des. batteries are paralleled
DPS Burn (Descent Simulation)	J10-4 Powered Descent & Landing	73:57:00	.201	.174	.027	2440.4	32.9/32.9	212.3/212.3	215.2/ 215.2	Des./Asc., Phase 3, (Same remarks as those for time of 73:49:20)
Post Burn C/O	J13-2 Descent Burn Docked	74:09:05	.083	--	.083	1896.3	78.6/78.6	--	78.6/ 78.6	Des./Asc., (Same remarks as those for time of 72:15:17), also a C/O of 20 min & 55 sec was assumed to simulate the lunar landing C/O, batteries still paralleled
Post Burn C/O	J12-2 Descent Burn Docked	74:14:05	.265	.096	.169	1896.3	320.5	182.0	502.5	Same remarks as those for time of 74:09:05 except the batteries are not paralleled

TABLE VII. - LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/104/LM-4 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, hr	Block rate, $\times 7\frac{1}{2}\%$, watts	5×6 watt-hr	Block energy, watt-hr	7 + 8 = total energy, watt-hr		Remarks
Two Men in LM on LM ECS	JL3-4 Crew Transfer From IM to CSM	74:30:00	.05	.05	--	1123.6	--	55.6	56.2	(Same remarks as those for time of 4:30:00 with the exception of 460.5 for GEN on)
One Man in LM on IM ECS	JL3-4 Crew Transfer From IM to CSM	74:33:00	.017	--	.017	1123.6	1.9.1	--	19.1	Des., Phase 2, Same remarks as those for the exception of 4:30:00 with the time of 4:30:00 for GEN on
SE in LM on CSM ECS (Dr./out water boiler)	J21-2 Subsystem Deactivation	74:34:00	1.375	.228	1.147	1138.6	1306.0	259.6	1565.6	Des., Phase 3, +204.3 for RCS heaters on, -695.7 for DFI off.
One Man in IM on CSM ECS (waiting)	JL3-4 Crew Transfer From IM to CSM	75:56:30	.058	--	.056	872.5	50.6	--	50.6	Des., Phase 3, (Same remarks as those for time of 7:33:00)
IM Power Off Coast	J26-4 Translunar Coast	76:00:00	13.0	--	13.0	95.2	1237.6	--	1237.6	CSM, Phase 5
Transfer 1st Crewman to IM	JL2-3 INV to IM	89:00:00	.097	--	.097	123.0	11.9	--	11.9	CSM, Phase 1
Transfer Electrical Power & Cabin Habitability C/O	JL2-3 INV to IM	89:05:50	.2	.2	--	815.6	--	163.1	163.1	Des., Phase 2
Transfer to IM ECS & Complete Crew Transfer	JL2-3 INV to IM	89:11:50	.211	.211	--	787.5	--	166.3	166.3	Des., Phase 3
C/O Two Men	JL4-3 Orbital C/O	89:30:30	.517	.278	.233	1782.8	426.1	495.6	921.7	Des., 1st Period, +688.3 for DFI off, +616.0 for RCS heater warmup

TABLE VII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS-5/104/LM-4 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Block time, hr	3 - 4 × 7 1/2%, watts	5 × 6 watt-hr	Block energy, watt-hr	7 + 8 = total energy, watt-hr		Remarks	7
C/O Two Men	JLh..3 Orbital C/O	90:01:29	.543	.239	1470.4	351.4	447.0	798.4	Des., 2nd Period, -688.3 for DFI off	
C/O Two Men	JLh..3 Orbital C/O	90:34:03	.495	.256	2390.0	571.2	611.6	1183.0	Des., 3rd Period, -688.3 for DFI off, +616.0 for RCS heater	
C/O Two Men	JLh..3 Orbital C/O	91:03:22	.447	.208	1906.8	455.7	396.6	852.3	Des., 4th Period, -688.3 for DFI off, a Δt of approximately 1 hr was added to the block	
Coasting	L27..4 Powered Up Coasting Flight	91:30:30	.147	--	.147	1951.0	286.8	--	286.8 Des., Phase a	
Coarse IMU Alignment	JIL..2 Docked IMU Alignment	91:39:18	.185	.065	.1	1798.9	179.9	152.9	332.8 Des., (Same remarks as those for time of 70:33:22)	
Coasting	L27..4 Powered Up Coasting Flight	91:50:23	1.315	1.0	.315	1951.0	614.6	1951.0	2565.6 Des., Phase a	
Fine IMU Alignment	JIL..2 Docked IMU Alignment	93:09:18	.194	.05	1819.9	91.0	262.1	353.1 Des., (Same remarks as those for time of 72:03:27)		
Prep for Burn	L8..2 Descent Burns (Auto)	93:20:58	.167	.167	--	1944.1	--	324.7	Des., -695.7 for DFI off and for A power between IM-2 & IM-3	
Parallel Ascent & Descent Batteries	L8..2 Descent Burns (Auto)	93:31:00	.083	.083	--	1944.1	--	80.7/80.7	80.7/ 80.7 Des./Asc., (Same remarks as those for time off 33:20:55)	

TABLE VIII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/104/LM-4 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Block time, hr	3 - 4 hr	Block rate \times 7 1/2%, watts	5 \times 6, watt-hr	Block energy, watt-hr	7 + 8 = total energy, watt-hr	Remarks	8
Descent Burn (SEP & initial phasing)	L8-2 Descent Burns (Auto)	93:36:00	.021	2199.7	46.2	--	--	46.2	Des., +255.6 for DPS on, also same remarks as those for time of 93:20:58	
Parallel Ascent & Descent Batteries	L8-2 Descent Burns (Auto)	93:37:15	.083	--	1944.1	--	80.7/80.7	80.7/80.7	Des./asc., also same remarks as those for time of 93:20:58	
Coasting	L27-4 Powered Up Coasting Flight	93:42:15	.094	--	.094	2360.5	221.0	--	221.9 Des., Phase a, +263.3 for tracking light on, +146.2 for RR on	
Fine IMU Alignment	L1-2 Undocked IMU Alignment	93:47:53	.194	.144	.05	2260.5	113.0	325.5	438.5 Des., $\Delta t=3$ min for orientation of 90° at .5°/sec, +23.7 for docking window heater on, 695.7 for DFI off, +146.3 for RR electronics on, +263.3 for tracking light on bright	
Prep for Transfer	L5-4 RCS Translation	93:59:33	.123	--	.123	2286.1	281.2	--	281.2 Des., Phase a, +7.5 for signal sensor on an unstated vehicle, +54.8 for Δ power on RCS heaters, +6.0 for EED on	
RCS Transfer (1st CS1)	L5-4 RCS Translation	94:06:00	.004	--	.004	2526.9	10.1	--	10.1 Des., +240.2 for TC4 on, also same remarks as those for time of 93:59:33	
Post Transfer Operation	L5-4 RCS Translation	94:06:15	.071	--	.071	2286.1	162.3	--	162.3 Des., (Same remarks as those for time of 93:59:33)	

TABLE VII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/104/LM-4 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, 3 - 4 hr	Block rate $\times 7 \frac{1}{2}\%$, watts	5×6 , watt-hr	Block energy, watt-hr	$7 + 8 =$ total energy, watt-hr	Remarks	
Coasting	L27-4 Powered Up Coasting Flight	94:09:05	.087	--	.087	2360.5	205.4	--	205.4 Des., (Same remarks as those for time of 93:42:15)	
Coarse IMU Alignment	L1-2 Undocked IMU Alignment	94:14:18	.174	.074	.1	2236.6	223.7	165.5	389.2 Des., $\Delta t=6$ min for orientation of 180° at 5°/sec, +3.7 for docking window heater on, -69.7 for DFI off, +146.3 for RR on, +263.3 for tracking light on	
Coasting	L27-4 Powered Up Coasting Flight	94:24:43	1.326	1.0	.326	2360.5	769.5	2360.5	3430.0 Des., (Same remarks as those for time of 93:42:15)	
Fine IMU Alignment	L1-2 Undocked IMU Alignment	95:44:18	.194	.144	.05	2260.5	113.0	325.5	438.5 Des., (Same remarks as those for time of 93:42:53)	
Prep for Burn	L8-2 Descent Burns (Auto)	95:55:58	.167	.167	--	2377.4	--	397.0	397.0 Des., +146.3 for RR on, +26.3 for tracking light on, -695.7 for DFI off	
Parallel Ascent & Descent Batteries	L8-2 Descent Burns (Auto)	96:06:00	.083	.083	--	2377.4	--	98.7/98.7	98.7/98.7 Des./Asc., also same remarks as those for time of 95:55:58	
Descent Burn (1st CDH)	L8-2 Descent Burns (Auto)	96:11:00	.009	--	.009	2633.0	23.7	--	23.2 Des., +25.6 for DPS on, also same remarks as for time of 95:55:58	
Parallel Ascent & Descent Batteries (Post DPS Burn)	L8-2 Descent Burns (Auto)	96:11:33	.083	.083	--	2377.4	--	98.7/98.7	98.7/98.7 Des./Asc., also same remarks as those for time of 95:55:58	

TABLE VII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/10b/LM-4 MISSION - Continued

10

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, hr	3 = 4 hr	Block rate $\times 7\ 1/2\%$, watts	5×6 , watt-hr	Block energy, watt-hr	$7 + 8 =$ total energy, watt-hr	Remarks
Coarse IMU Align- ment	LM-2 Undocked IMU Alignment	96:16:33	.174	.074	.1	2236.6	223.7	165.5	389.2	Des., (Same remarks as those for time of 94:11:18)
Coasting	LM-4 Powered Up Coasting Flight	96:26:58	1.320	1.0	.320	2360.5	755.4	2360.5	3115.9	Des., Phase a, (Same remarks as those for time of 93:4:21:15)
Fine IMU Alignment	LM-2 Undocked IMU Alignment	97:46:13	.194	.144	.05	2260.5	113.0	325.5	325.5	Des., (Same remarks as those for time of 93:4:7:53)
Pre-FITH Activities	L25-3 FITH	97:57:53	.252	.252	--	2369.5	--	597.1	597.1	Phase 1, +263.4 for tracking light on, +146.2 for RR on, +23.7 for docking window heater on, -688.3 for DFT off
AFS Burn (2nd CSI)	L25-3 FITH	98:13:00	.001	--	.001	2592.9	2.6	--	2.6	Phase 2, +223.4 for AFS on, also same remarks as those for time of 97:5:53
Post FITH Activities	L25-3 FITH	98:13:04	.047	.047	--	2314.7	--	108.8	108.8	Phase 3, also same remarks as those for time of 97:5:53
Coasting (Subsystem Check)	LM-4 Powered Up Coasting Flight	96:15:54	.255	--	.255	2233.5	569.5	--	569.5	Phase c

TABLE VII. - LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/104/LM-4 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, hr	Block rate $\times 7\frac{1}{2}\%$, watts	5×6 , watt-hr	Block energy, watt-hr	$7 + 8 =$ total energy, watt-hr	Remarks	
Fine IMU Alignment	L1-2 Undocked IMU Alignment	96:31:13	.194	.144	.05	2167.7	108.4	312.1	420.5	$\Delta t=3$ min for start orientation (90° at 0° sec), -16.3 for IR heater off, -10.7 for ASC ECA being on instead of DES ECA, -3.7 for signal sensors being on a staged instead of unstaged LM, -54.8 for RCS heater correction, +263.4 for tracking light on, +146.2 for RR on, +23.7 for docking window heater on, -695.7 for DFI off
Prep & Orient for AFS Burn	L9-2 Ascent Burns (Auto)	96:42:23	.234	.009	.025	2238.4	56.0	467.8	523.8	$\Delta t=1.5$ min for attitude orientation, +23.7 for docking window heater or, +146.2 for RR on, +23.4 for tracking light on, -54.8 for RCS heater correction, -695.7 for DFI off
AFS Burn (CDH)	L9-2 Ascent Burns (Auto)	96:53:00	.001	--	.001	2468.1	2.5	--	2.5	+223.4 for AFS on, the rest would be the same as for time of 27:42:53
Post AFS Burn Activities	L9-2 Ascent Burns (Auto)	97:58:04	.047	.047	--	2228.4	--	105.2	105.2	Same remarks as those for time of 97:25:22
Coasting	L27-4 Powered Up Coasting Flight	99:00:54	.185	--	.135	2233.5	413.2	--	413.2	Phase C

TABLE VII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/104/TM-4 MISSION - Continued

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Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Block time, hr	3 - 4 \times 7 1/2% watts	Block rate, watt-hr	5 \times 6, watt-hr	Block energy, total watt-hr	7 + 8 = total energy, watt-hr	Remarks	
Fine IMU Alignment	JL-2 Undocked IMU Alignment	99:11:59	.194	.05	2167.7	108.4	312.1	420.5	Same remarks as those for time of 97:31:13	
Prep for Transfer	JL-4 RCS Translation	99:23:39	.123	--	.123	2217.8	272.8	--	272.8 Phase a	
RCS Transfer (TPF)	JL-4 RCS Translation	99:31:00	.007	--	.007	2158.6	17.2	--	17.2 Phase a, +240.8 for TCA on	
Post Transfer Operation	JL-4 RCS Translation	99:31:25	.071	--	.071	2217.8	157.5	--	157.5 Phase a	
Coasting	JL-4 Powered Up Coasting Flight	99:34:15	.212	--	.212	2233.5	473.5	--	473.5 Phase c	
Fine IMU Alignment	JL-2 Undocked IMU Alignment	99:46:59	.194	.144	.05	2167.7	108.4	312.1	420.5 Same remarks as those for time of 97:31:13	
Prep for Transfer	JL6-3 Terminal Phase Final	99:58:39	.123	--	.123	2168.6	266.7	--	266.7 +236.5 for A wattage between tracking light on bright and dim, -688.3 for DFI off	
RCS Transfer (TPF)	JL6-3 Terminal Phase Final	100:06:00	.028	--	.028	2409.4	67.5	--	67.5 +240.8 for TCA on, the rest of the remarks are those for time of 98:58:39	
Post Transfer Operation	JL6-3 Terminal Phase Final	100:07:40	.071	--	.071	2168.6	154.0	--	154.0 Same remarks as those for time of 98:58:39	
Docking Maneuvers & Initial Post Docking Activities	JL7-3 LM Active Docking	100:10:30	.129	.129	--	1889.5	--	243.2	243.2 Phase 1, -638.3 for DFI off	
Subsystem Deactivation & Preparation for Transfer	JL7-3 LM Active Docking	100:15:15	.233	.233	--	1274.1	--	296.9	296.9 Phase 2	

TABLE VII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/LM-4 MISSION - Continued

Column number	1	2	3	4	5	6	7	8	9	10
Phase name	Block number and title	Mission time, hr:min:sec	Phase time, hr	Block time, hr	Block rate, $\times 7 1/2\%$, watts	5×6 , watt-hr	Block energy, watt-hr	$7 + 8 =$ total energy, watt-hr		Remarks
Prior to CDR Transfer to CSM ECS in IM	JL3-4 Crew Transfer From IM to CSM	100:37:15	.05	1169.1	--	58.5	58.5	58.5	Phase 1	
ECS in IM	JL3-4 Crew Transfer From IM to CSM	100:35:15	.283	1169.1	--	330.9	330.9	330.9	Phase 2	
SE in IM on CSM ECS (dryout water boiler)	L21.2 Subsystem Deactivation	100:52:15	1.5	1.5	1053.1	1579.7	--	1579.7	Phase 3, -1c.3 for RR heater off, -10.7 for ascent ECA being on instead of DES, -3.7 for signal sensors being on a staged instead of unstaged LM, +4150.5 for RCS heaters on, -695.7 for DFI off	
One Man in IM on CSM ECS (waiting)	JL3-4 Crew Transfer From IM to CSM	102:22:18	.069	1236.5	--	85.3	95.3	95.3	Phase 4	
LM Power Off Coast	LC6-4 Translunar Coast	102:26:28	24.0	24.0	61.0	1464.0	--	1464.0	CSM, Phase 5, -10.8 for ASC ECA being on instead of DES, -23.4 for IR heater off	
Clear Tunnel & Transfer 1st Crewman to IM	JL6-3 INV to LM	126:26:28	.097	.097	104.5	104.1	--	10.1	10.1	CSM, Phase 1, -18.5 for IR heater off
One Man in IM on CSM ECS	JL5-4 Crew Transfer From IM to CSM	126:32:18	.228	.228	1207.4	--	275.3	275.3	ASC, Phase 3, +263.4 for tracking light on	
One Man in IM on CSM ECS (Transferring back to CSM)	JL5-4 Crew Transfer From IM to CSM	126:35:58	.069	.069	1225.0	--	84.5	84.5	84.5	Asc., Phase 4, +263.4 for tracking light on

TABLE VII.- LM ELECTRICAL POWER ANALYSIS FOR THE AS-505/104/LM-4 MISSION - Concluded

Column number Phase name	1 Block number and title	2 Mission time, hr:min:sec	3 Phase time, hr	4 Block time, hr	5 3 - 4 hr	6 Block rate $\times 7\frac{1}{2}$, watts	7 5×6 , watt-hr	8 Block energy, watt-hr	9 $7 + 8 =$ total energy, watt-hr	10 Remarks
Prep for Jettison (warm-up)	JL-2-3 ATS Burn to Depletion	126:40:08	.601	.101	.5	1137.4	563.7	114.8	683.5	Phase 1, -688.3 for DFI off, +263.4 for tracking light on, -173.5 for ASA & AEA off, $\Delta t=30$ min for warm-up, -34.3 for docking light off.
Post Jettison Coast	JL12-3 APS Burn to Depletion	126:46:13	--	--	--	1137.4	--	--	--	Phase 1, (Same remarks as those for time of 125:40:08)

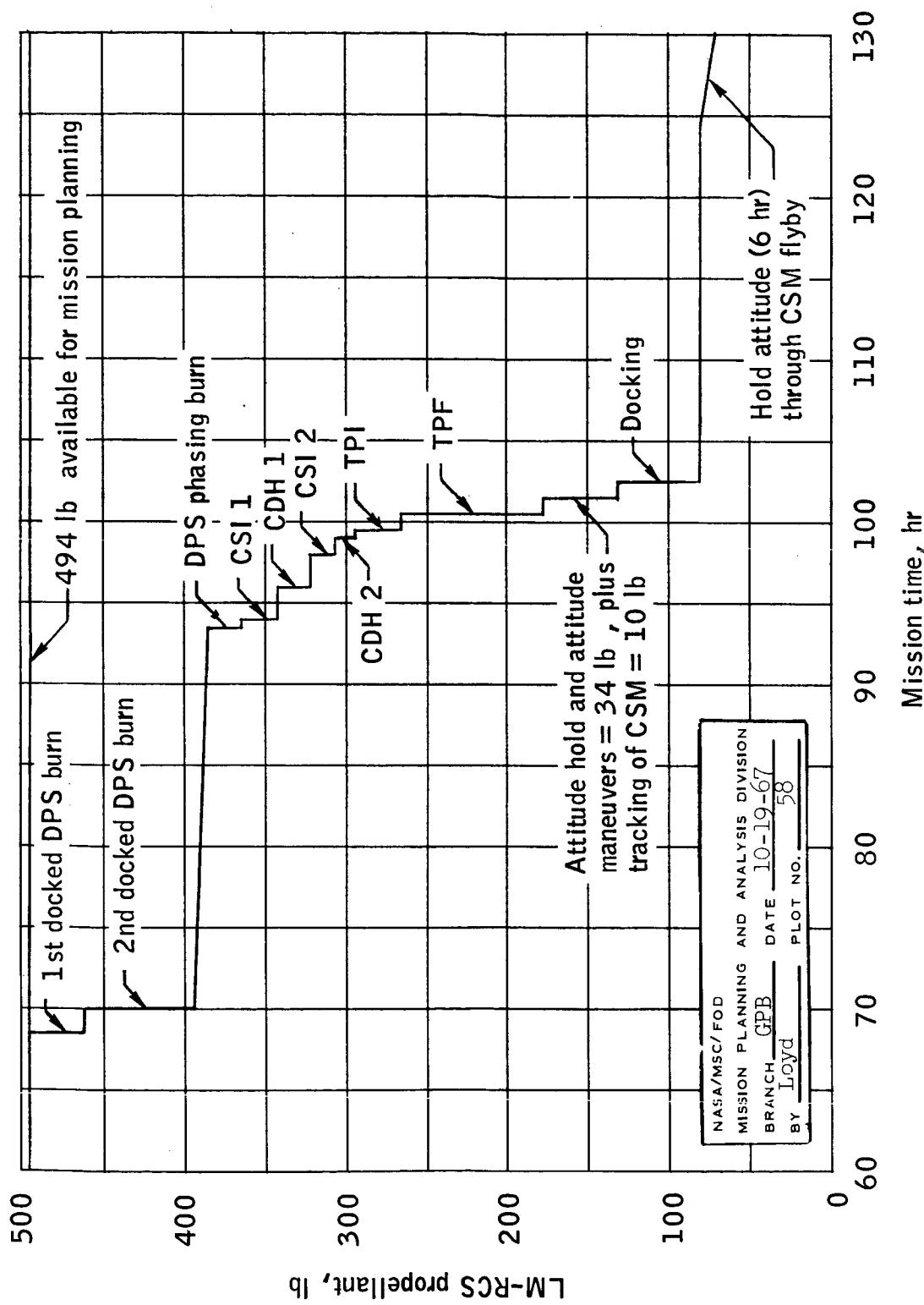


Figure 1.- LM-RCS propellant profile Model B-2," LM-active rendezvous.

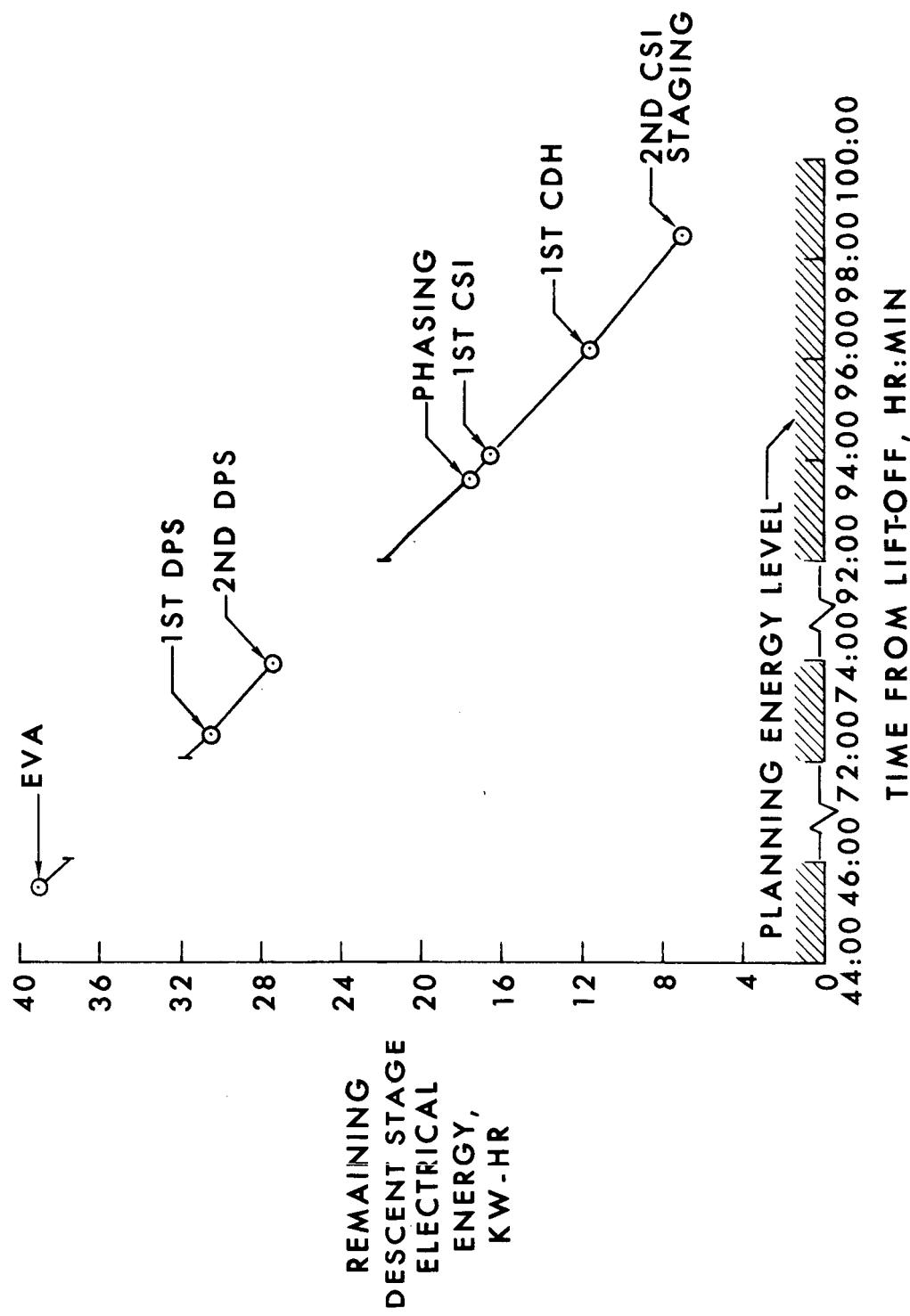


Figure 2.- Descent electrical energy consumption for the B-2¹¹ rendezvous scheme.

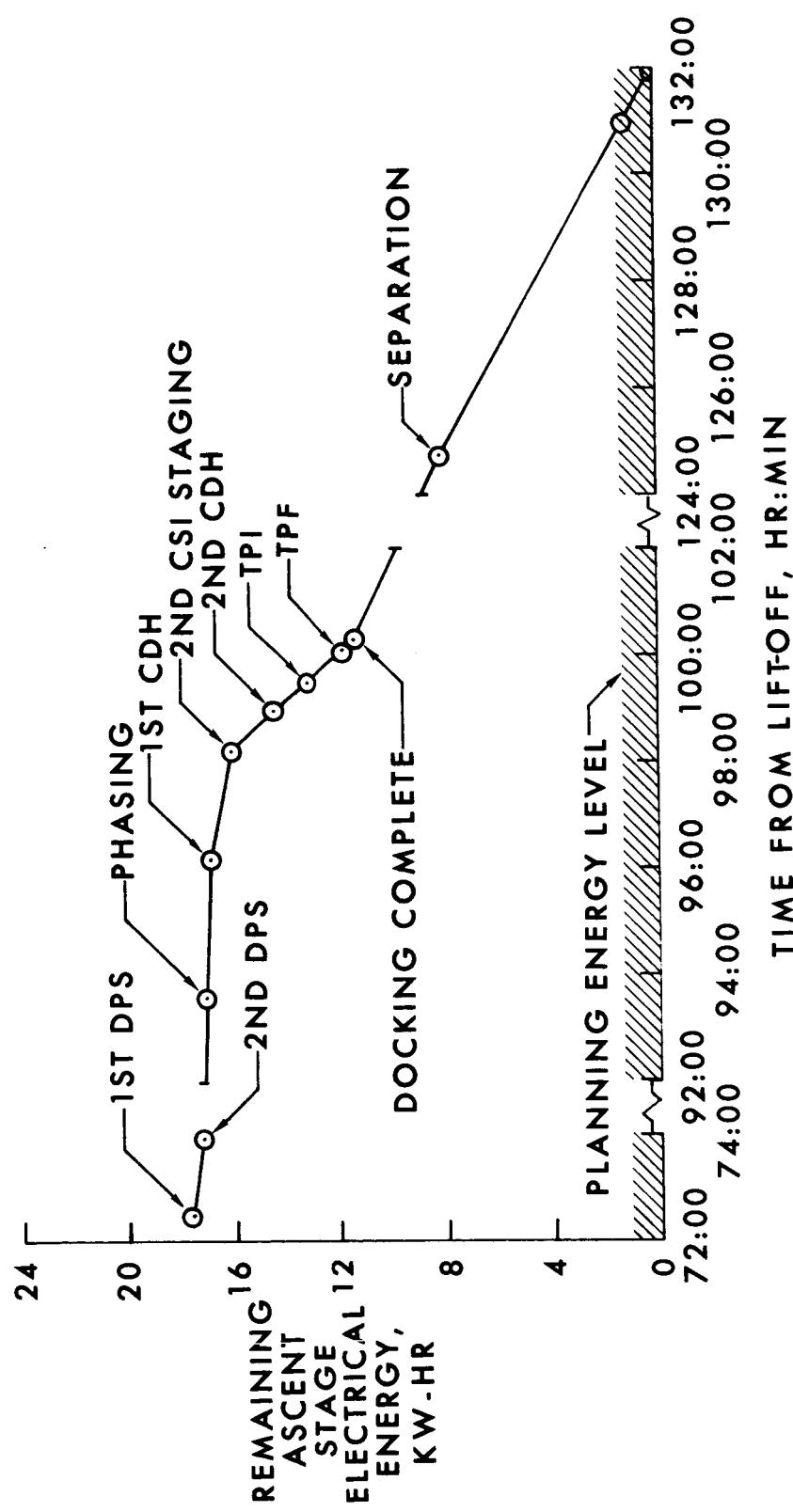


Figure 3.- Ascent electrical energy consumption for the B-2" rendezvous scheme.

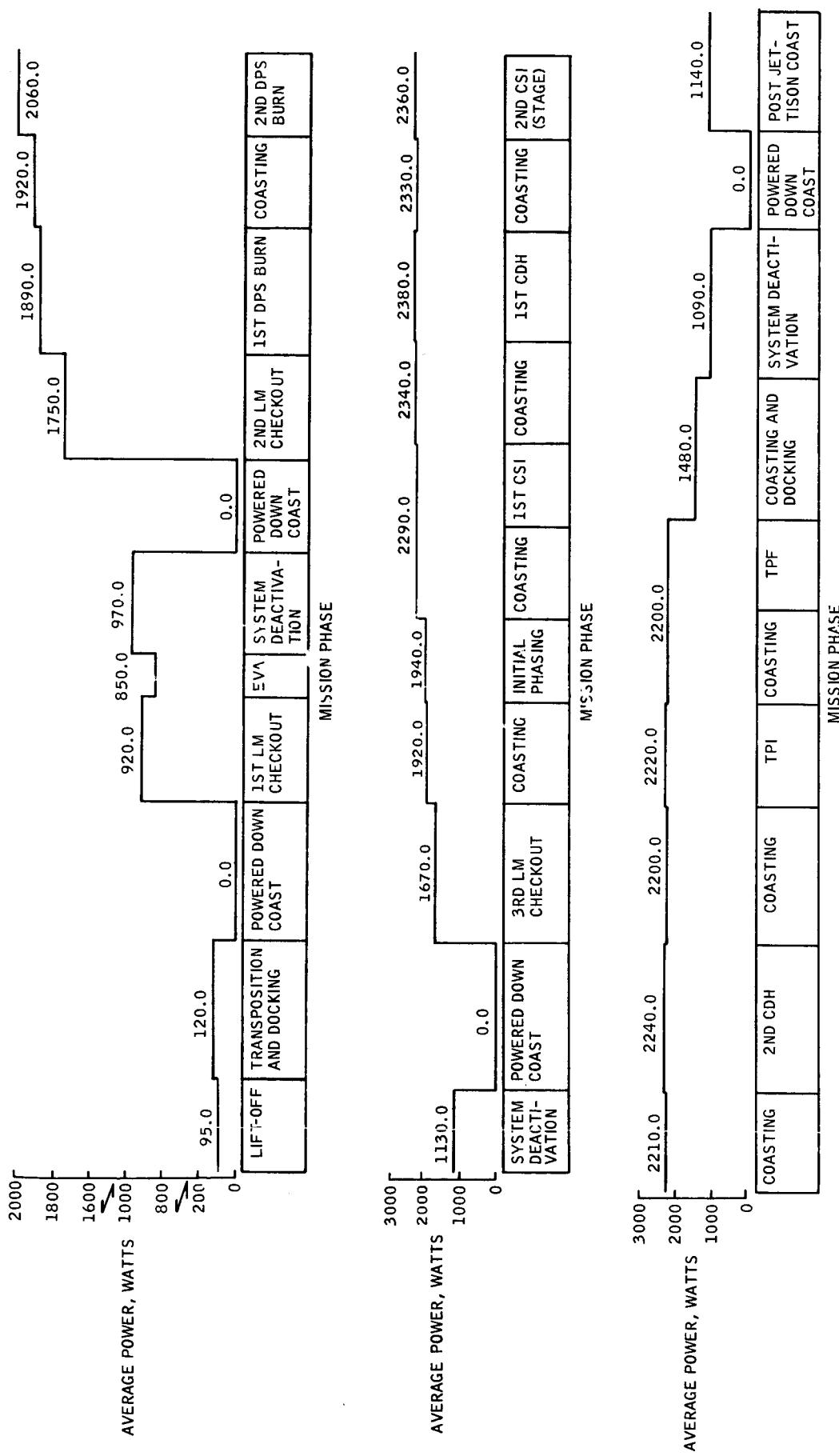


Figure 4. - Average power levels for mission AS-505/CSM-104/LM-4.

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